Taxonomy and Comparative Study of NDN Forwarding Strategies

NARJES ALOULOU, CRISTAL LAB (TUNISIA)

MOUNA AYARI, LIP6 LAB (FRANCE)

MOHAMED FATEN ZHANI, ÉTS (CANADA)

LEILA SAIDANE, CRISTAL LAB (TUNISIA)
Outline

- Introduction
- Overview of Named Data Networking (NDN)
- Taxonomy of NDN Forwarding Strategies
- Comparison Study of NDN Forwarding Schemes
- Conclusions
Introduction

- Internet data traffic has grown significantly due to the rapid growth in demand for multimedia content.

- Recent statistics show that:
  - over 6 billion hours of video are watched each month on Youtube
  - with 100 hours video uploaded every minute in 2013 (50\% more than 2012).
  - More than 350 million images are uploaded on Facebook each day.

![Internet Traffic Forecast](image-url)
Introduction

67% of Internet Traffic

Users are more interested in data (content) than in end-to-end communication
Introduction

Today’s Internet

- End-to-end host communication
- Communication centered around host addresses

Where is the server hosting my data?

IP based Routing

Internet usage has shifted

Named Data Networking

- New communication model is known
- Communication centered around data
- Focusing on data content names instead of the addresses of the end-to-end hosts.

Where is my Data?

Name-based Routing

Host A

Host A @IP-1

Server Host B @IP_2

@IPsource, @IPDest.

Today’s Internet

- End-to-end host communication
- Communication centered around host addresses

Where is the server hosting my data?

IP based Routing

@IPsource, @IPDest.

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March 31, 2017, Hammamet, TUNISIA
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Named Data Networking (NDN)

- Promising candidate for the future Internet architecture
  - Centered around data
  - Data (content) is identified by a name
  - A router can keep the data in its cache and serve it to users

- Two types of packets
  - **Interest packets**: containing the name of the requested data
  - **Data packet**

**Content Store**: a cache of data packets that the router has received
Named Data Networking (NDN)

- NDN router maintains three data structures
  - **Content Store**: temporary cache data packets
  - **Pending Interest Table (PIT)**: keeps track of the unsatisfied interest packets forwarded through the router
  - **Forwarding Information Table (FIB)**: used to forward interest packets towards the potential sources of data.
NDN Challenges

→ Numerous challenges should be carefully addressed in order to make NDN a viable technology

→ NDN suffers from a problem of inefficiency of its default caching and forwarding modules.

- **Basic Forwarding approach:** Content requests are forwarded to all available interfaces in the FIB entry matching the requested content’s prefix except the incoming one.
  → High overhead

- **Basic Caching strategy:** A copy of the requested data is stored in all intermediate routers along the path from cache hit node to the user.
  → High cache redundancy in the network
Our Goals

1. Propose a new taxonomy of NDN Forwarding Strategies

2. Provide a comparison study of the main NDN Forwarding Schemes
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Taxonomy of NDN Forwarding Strategies

- Strategies Based on Routing History Traces
  - S-BECONS
  - CLS
  - SAC
  - COBRA
  - ...

- Strategies Based on Exploration Step
  - INFORM
  - Probabilistic Forwarding (EPF, MDPF)
  - ...

- Strategies Based on Preselected Responsible Routers
  - CollaCache
  - CoRC
  - CCFS
  - ...

- Strategies Based on Explicit Cache Coordination
  - NbSc
  - ACCCP
  - SCAN
  - ...

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# NDN Forwarding strategies

<table>
<thead>
<tr>
<th>NDN Forwarding Strategies</th>
</tr>
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<tbody>
<tr>
<td>Basic NDN</td>
</tr>
<tr>
<td>COBRA</td>
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<tr>
<td>INFORM</td>
</tr>
<tr>
<td>NbSc</td>
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<tr>
<td>CCFS</td>
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</table>
NDN Forwarding strategies

- Forwarding based on flooding.
- Leaving a copy of data in the in-path nodes.
- On receiving an Interest: Router checks first its local CS.
  - Data returned if exists
  - Otherwise, the router adds the incoming interface in PIT if there is an entry, if not it will be sent following the FIB routers.
- Data will be returned back when a hit occur.

Neglecting the closed copy in the vicinity

NDN Forwarding strategies

**Basic NDN**

- Uses Stable BloomFilters (SBF) to leave traces of retrieved contents
- Replaces classical FIB by a SBF-based FIB
  - As many SBFs as the router’s interfaces.
- On receiving an Interest => Performs an interface ranking based on Longest Prefix Match (LPM) (at each lookup).
  - The more a SBF matches name content, the higher the associated interface is ranked.
  - The most ranked interface is used

- Does not **scale** with the network size.
- COBRA will converge to the Basic NDN.

**COBRA**

**NDN Forwarding strategies**

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**Exploration phase**: Interests are forwarded via randomly chosen faces in addition to the default FIB faces

- Discovered sources of content are then added to the FIB
- Adding discovered sources of content to FIB

**Exploitation phase**: node uses this information to forward the content request towards the closest available cached content copy in terms of estimated residual delay.

😊 Interesting proposed learning framework

😢 Randomly replicating and flooding Interests to all nodes faces could end up with face congestion problems and scalability issues.

NDN Forwarding strategies

- **Neighborhood Search protocol**: Exchanges periodically cache BF summaries (Bloomfilter based) between immediate neighbors.
  - Received BFs are stored in a neighbor table.
    - Used to check the content availability in the neighborhood in the case of a cache miss.

- **Cooperative caching strategy based on a Cachebit algorithm**: Using a bit in the content header to indicate whether a data content has already been cached along the path.
  - Admission control policy: if cache bit setten=> Prevents the downstream nodes to cache data.

Improving the chances of off-path content discovery.
Limits the availability of in-path data.

NDN Forwarding strategies

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- Divide the network into **domains** managed by cooperative controllers
- Each domain: **1 Controlling router + Regular NDN Routers**
- Each controller has a global cache view (intra and inter-domain)
- Each controller is responsible for taking interest forwarding decisions and ensure the availability of high popular data in its domain
- Hybrid cache coordination approach: implicit intra-domain and explicit between neighbor Controllers
- Consider additional objectives: Load balancing among controllers

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Qualitative Comparaison

we consider the following main criteria.

- **Additional information**: a complementary structures as a part of their design
- **Cache visibility**: the scope of awareness regarding in-network cached data.
- **Cache coordination**: the method used for coordinating storage decisions between cache nodes
- **Popularity-driven**: takes into consideration the content popularity or not
- **Searching policy**: defines the way to search a content when an Interest is received before taking the forwarding decision.
- **Caching and forwarding operational mode**: coupled mode when the caching and the forwarding decisions are jointly considered and uncoupled if they are independent.
## Qualitative Comparison

<table>
<thead>
<tr>
<th>Solution</th>
<th>Additional-Info</th>
<th>Cache visibility</th>
<th>Cache coordination</th>
<th>Popularity-driven</th>
<th>Searching policy</th>
<th>Caching &amp; forwarding operational mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic NDN</td>
<td>No</td>
<td>Local</td>
<td>Noncooperative caching</td>
<td>No</td>
<td>default NDN</td>
<td>Uncoupled</td>
</tr>
<tr>
<td>COBRA</td>
<td>FIB modified by adding SBFs and interfaces Ranks to each entry</td>
<td>Local</td>
<td>Implicit</td>
<td>No</td>
<td>Query forwarding according to routing hints established by SBF-based FIB</td>
<td>Uncoupled</td>
</tr>
<tr>
<td>INFORM</td>
<td>FIB modified by adding Q-Values</td>
<td>Local</td>
<td>Noncooperative caching</td>
<td></td>
<td>Q-Routing</td>
<td>Uncoupled</td>
</tr>
<tr>
<td>NbSc</td>
<td>Neighborhood index Table</td>
<td>Local+ neighborhood</td>
<td>Explicit</td>
<td>No</td>
<td>Neighbor-hood Search based on index table</td>
<td>Coupled</td>
</tr>
<tr>
<td>CCFS</td>
<td>Cache Information Base (CIB)</td>
<td>@regular routers: local; @Controllers: neighborhood</td>
<td>Implicit(intra-domain) &amp; explicit (inter-domain)</td>
<td>Yes</td>
<td>Controller- based query forwarding according to index tables (FIB and CIB) based on the popularity of the requested content</td>
<td>Coupled</td>
</tr>
</tbody>
</table>
Simulation setup

- We compared Basic NDN, COBRA, INFORM, NbrSc and CCFS

Performance Metrics
- Mean Latency: time refers to the average time taken by a complete content (i.e., a file)
- Throughput: the average amount of data received successfully by a client in one second
- Interest overhead: the data retrieval overhead generated in the network
- Cache Hit Ratio: fraction of requests served by the cache.

- We studied the impact of the variation of the Cache size Per router
# Simulation setup

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chunk size</td>
<td>10 KB</td>
</tr>
<tr>
<td>File size</td>
<td>Uniform distribution (100 chunks per file ➔ average file size =1MB)</td>
</tr>
<tr>
<td>Catalog size</td>
<td>10⁶ files</td>
</tr>
<tr>
<td>Cache/catalog ratio</td>
<td>{0.01 % ..0.1 %} of all Content</td>
</tr>
<tr>
<td>Zipf exponent $\alpha$</td>
<td>{0.8,1,1.2,1.4}</td>
</tr>
<tr>
<td>Request rate (per client)</td>
<td>50 chunks/s</td>
</tr>
<tr>
<td>Cache replacement policy</td>
<td>Least frequently Used (LFU)</td>
</tr>
<tr>
<td>Network simulator</td>
<td>NDN-sim</td>
</tr>
<tr>
<td>Number of interests per user</td>
<td>90000</td>
</tr>
<tr>
<td>Simulation duration</td>
<td>48 hours</td>
</tr>
<tr>
<td>Network topology</td>
<td>Geant network (22 core routers, 73 edge routers and 255 clients)</td>
</tr>
</tbody>
</table>
Simulation Results

Impact of Cache Size

(a) Average Throughput (KB/s) vs. Cache Size Per Router (% of all contents)

(b) Mean Latency (ms) vs. Cache Size Per Router (% of all contents)

(c) Cache Hit Ratio vs. Cache Size Per Router (% of all contents)
Simulation Results

Impact of Cache Size

(a) Cache Size Per Router (% of all contents)

(b) Cache Size Per Router (% of all contents)
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Conclusions

- Propose a new taxonomy of NDN Forwarding strategies
  - Classify the NDN forwarding strategies into four categories based on their basic functional designs to support the Interest forwarding decision

- Survey the main proposals and identified their advantages and limitations

- Main Observations
  - A coupled operational mode of Caching and Forwarding schemes reduces significantly the Interest Overhead in the network
  - A Popularity-driven design improves the forwarding efficiency
Thank you for your attention
Any question?
CCFS Overview

- Controller-based Forwarding Strategy
  - If a router has the requested data, it sends it back to the user
  - Otherwise, the interest has to be handed up to the controllers

- Hybrid cache coordination
  - Implicit intra-domain coordination: The controller implicitly builds a cache view of the content stored in its domain
  - Explicit inter-domain coordination: Each Controller periodically informs neighboring controllers about available data in its domain

- Popularity-driven caching admission policy
  - High Popular content is cached in the Controllers CS
  - Low Popular content is cached in the Regulars CS

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CCFS - Overview

**NDN Regular Router Structure**
- Local cache awareness limited to the CS

**NDN Controller Router Structure**
- Local and Neighborhood cache awareness

**Cache information base (CIB):** a new table that has as many entries as the Controller’s interfaces towards local regular routers and its neighbouring Controllers

<table>
<thead>
<tr>
<th>Face ID</th>
<th>Type</th>
<th>SBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Regular</td>
<td>10101010100101000101</td>
</tr>
<tr>
<td>3</td>
<td>Controller</td>
<td>11110000010101011111</td>
</tr>
<tr>
<td>5</td>
<td>Regular</td>
<td>00100011111010101010</td>
</tr>
</tbody>
</table>
CCFS - Overview

- Basic Idea:
  - If a router has the requested data, it sends it back to the user
  - Otherwise, the interest has to be handed up to the controllers

**Controller: Interest Forwarding**
- If there is an entry in the CIB matching the footprint of the requested content
  - Forward the Interest to the matching interface
- Otherwise, Forwards the Interest according to the FIB.

**Regular: Interest Forwarding**
- If the incoming interface is the controller
  - Forward the Interest according to the FIB
- Otherwise, Forward the Interest to the controller